Joining and Assembly of Bulk Metallic Glass Composites Through Capacitive Discharge

Commercial uses include spacecraft debris shielding, energy-absorbing panels on military vehicles, and sporting goods.

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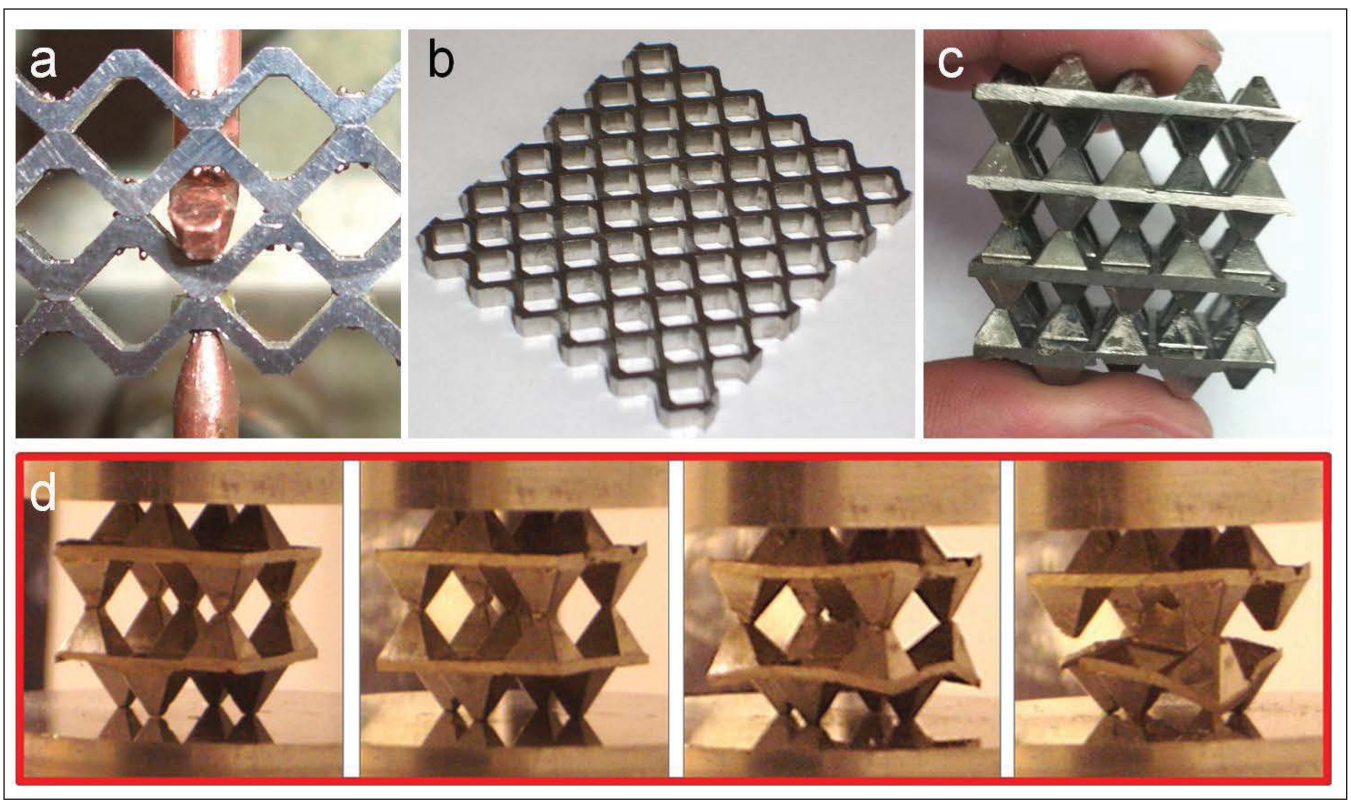
Bulk metallic glasses (BMGs), a class of amorphous metals defined as having a thickness greater than 1 mm, are being broadly investigated by NASA for use in spacecraft hardware. Their unique properties, attained from their non-crystalline structure, motivate several game-changing aerospace applications. BMGs have low melting temperatures so they can be cheaply and repeatedly cast into complex net shapes, such as mirrors or electronic casings. They are extremely strong and wear-resistant, which motivates their use in gears and bearings. Amorphous metal coatings are hard, corrosion-resistant, and have high reflectivity. BMG composites, reinforced with soft second phases, can be fabricated into energy-absorbing cellular panels for orbital debris shielding.

One limitation of BMG materials is their inability to be welded, bonded, brazed, or fastened in a convenient method to form larger structures. Cellular structures (which can be classified as trusses, foams, honeycombs, egg boxes, etc.) are useful for many NASA, commercial, and military aerospace applications, including low-density paneling and shields. Although conventional cellular structures exhibit high specific strength, their porous structures make them challenging to fabricate. In particular, metal cellular structures are extremely difficult to fabricate due to their high processing temperatures. Aluminum honeycomb sandwich panels, for example, are used widely as spacecraft shields due to their low density and ease of fabrication, but suffer from low strength.

A desirable metal cellular structure is one with high strength, combined with low density and simple fabrication. The thermoplastic joining process described here allows for the fabrication of monolithic BMG truss-like structures that are 90% porous and have no heat-affected zone, weld, bond, or braze. This is accomplished by welding the nodes of stacked BMG composite panels using a localized capacitor discharge, forming a single monolithic structure. This removes many complicated and costly fabrication steps. Moreover, the cellular structures detailed in this work are among the highest-strength and most energy-absorbent



BMG Features: (a) Enlarged view of capacitive discharging technique used to fuse BMG cellular structures. (b) A BMG composite honeycomb sandwich panel joined using the new technique. (c) A four-layer BMG composite foam fabricated by joining each node of adjacent panels into a single monolithic structure. (d) A compression test in a two-layer welded structure showing buckling and eventual fracture of the welded joints.

materials known. This implies that a fabricated structure made from these materials would have unequaled mechanical properties compared to other metal foams or trusses.

The process works by taking advantage of the electrical properties of the matrix material in the metal-matrix composite, which in this case is a metallic glass. Due to the random nanoscale arrangement of atoms (without any grain boundaries), the matrix glass exhibits a near-constant electrical resistivity as a function of temperature. By placing the composite panels between two copper electrode plates and discharging a capacitor, the entire matrix of the panel can be heated to approximately 700 °C in 10 milliseconds, which is above the alloy's solidus but below the liquidus. By designing the geometry of the panels into the shape of an egg box, the electrical discharge localizes only in the tips of each pyramidal cell. By applying a forging load during discharge, the nodes of the panels can be fused together into a single piece, which then dissipates heat through radiation back into a glassy state. This means that two panels can be metallurgically fused into one panel with no heat-affected zone, creating a seamless connection between panels. During the process, the soft metal particles (dendrites) that are uniformly distributed in the glassy matrix to increase the toughness are completely unaffected by the thermoplastic joining. The novelty is that a truss (or foam-like) structure can be formed with excellent energy-absorbing capabilities without the need for machining. The technique allows for large-scale fabrication of panels, well-suited for spacecraft shields or military vehicle door panels.

Crystalline metal cellular structures cannot be fabricated using the thermoplastic joining technique described here. If metal panels were to be assembled into a cellular structure, they would either have to be welded, brazed, bonded, or fastened together, creating a weak spot in the structure at each connection. Welded parts require a welding material to be added to the joint and exhibit a soft and weak heat-affected zone. Brazing and bonding do not form a metallurgical joint and thus exhibit low strengths, especially when the panels are pulled apart and fasteners require high-stress-concentration holes to be drilled. No equivalent rapid heating method exists for assembling metal panels together into cellular structures, and thus, those parts must be foamed, machined, or investment cast if they are to form a monolithic structure. If the crystalline panels were to be joined using capacitive discharge, as with a spot welder, their bond would be very weak, and the panels would have to be extremely thin. In contrast, the strength of joined BMG parts has been demonstrated to have strength comparable to the parent material. This technique opens up the possibility of using large-scale BMG hardware in spacecraft, military, or commercial applications.

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